Project Report

EE381K

Multiuser Wireless Communications

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Multi-User Diversity for MIMO-OFDM Systems

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Abstract

In this project, a multiuser diversity scheme for MIMO-OFDM systems has been proposed to improve system performance. In the space-time MIMO-OFDM system with multiuser, it needs a scheduler at the base station to do the spatial multiplexing. The scheduler distributes sub-channels to different users based on the feedback channel state information (CSI). The goal is that each user determines a limited feedback CSI under his data rate requirement and the scheduler dispatches sub-channels to each user according to feedback CSI. The simulation results demonstrate that the proposed scheduler can significantly improve the system performance with limited feedback CSI.

1. Introduction

In the past years, the research has proved that performance can be improved by scheduling, power allocation, or adaptive modulation for CDMA, OFDM, and MIMO systems. OFDM can support high data rate transmission over wireless channels by multiplexing technique. In [1], several techniques have been discussed briefly to improve system performance and spectral efficiency for multiuser OFDM. These include adaptive modulation and adaptive user allocation. An adaptive modulation algorithm with bit and power allocation for multiuser OFDM has been studied in [2]. The objective is to minimize the total transmit power for given transmission rate of the users and given QoS requirements. Another approach [3] for dynamic subchannel allocation was to increase the capacity of multiuser OFDM system by maximizing the smallest capacity of all users.

Recent research also shows that the rich-scattering wireless channel is capable of enormous theoretical capacities if the multipath is properly exploited [4-5]. The MIMO wireless communication architecture, knows as V-BLAST [5], which deploys multiple antennas at both transmitter and receiver had been demonstrated spectral efficiencies of 20 – 40 bps/Hz.

Due to high spectral efficiencies of OFDM, MIMO, and MIMO-OFDM systems, a multiuser diversity scheme can be applied to these systems. In [6], the concept of multiuser diversity has been discussed briefly which includes a fair scheduling for IS-856 system. To improve system performance, the basic idea of diversity is creating several different and independent transmitting paths from the transmitter to the receiver. The conventional diversity can be obtained over frequency, time, and space. Due to the characteristic of wireless network with multiple users, there are several users can receive the signal from the transmitter. Therefore, the transmitter establishes different signal paths to different users. This called multiuser diversity, the transmitter selects an appropriate user to improve performance. This condition can be maximizing channel capacity or maximizing average throughput over users. If system transmits to users with large SNR channel at all times, the overall spectral efficiency of the system can be reached significantly higher than that of a nonfaded channel. . An application of multiuser diversity for MIMO system has been studied in [7]. This paper proposed a number of different scheduling schemes for MIMO spatial multiplexing systems with perfect channel knowledge. In [8], the practical implementation and consideration of multiuser diversity for CDMA/HDR was discussed.

When OFDM operated with MIMO techniques, there are multi-dimensional parameters can be adapted for radio resource allocation, such as code, tone, time, and space. In [9], the authors proposed an iterative bit and power allocation schemes for V-BLAST based MIMO-OFDM systems. The algorithm is based on the detection method of V-BLAST to allocate the sub-channels to single user according to his bit error rate requirement. The same research teams also present a simplified bit allocation for V-BLAST MIMO-OFDM system [10]. The new algorithm requires one bit for feedback CSI. It's more efficiency to allocation resource to single user. However, these two algorithms only consider the single user case. Hence, we can apply the multiuser diversity technique to such systems.

In this project we describe a multisuer diversity scheme for MIMO-OFDM systems that uses V-BLAST as a detection algorithm. This scheme includes two parts, first is determination of feedback CSI which is based on the V-BLAST algorithm. The other one is a scheduler which allocates sub-channels to different users according to their CSI. We can apply the optimization problem, integer linear programming, to the scheduler for channel allocation.

This paper is organized as follows. In Section 2 we introduce the system model of MIMO-OFDM system and in Section 3 the V-BLAST detection algorithm is described. In Section 4, we propose the multiuser diversity scheme for MIMO-OFDM systems. Then we compare the system performance with different feedback CSIs in Section 5. Finally, a conclusion is made in Section 6.

2. System Model

A simple model for the downlink of a V-BLAST based MIMO-OFDM system is illustrated in Figure 1. The base transceiver station (BTS) has Mt transmit antennas while each antenna transmits N_c sub-carrier signals. In total, there are $M_t \times N_c$ sub-channels. A queue of packets is stored at the BTS for each of the K users. Based on feedback CSIs from users, the BTS allocate several sub-channels to user k to send the data packets of length $R^k{}_b$. Therefore,

$$\sum_{i=1}^{M_t}\sum_{c=1}^{N_c} B \cdot x_{i,c}^k \le R_b^k \qquad \forall\, k \tag{1}$$

where $x_{i,c}^k$ is the sub-channel allocated for user k, B is the number of bits per sub-channel. Here, we assume that an ordinary M-QAM signal constellation is being user in the modulation.

At the receiver side, there are M_r receive antennas for each user. The received signal from all receive antennas will pass through a Fast Fourier Transform. We assume that the path delays for all the spatial channels are the same. Furthermore, perfect symbol timing synchronization and perfect channel estimation is assumed. There signals will be processed by using the V-BLAST detection algorithm to retrieve the original signal.

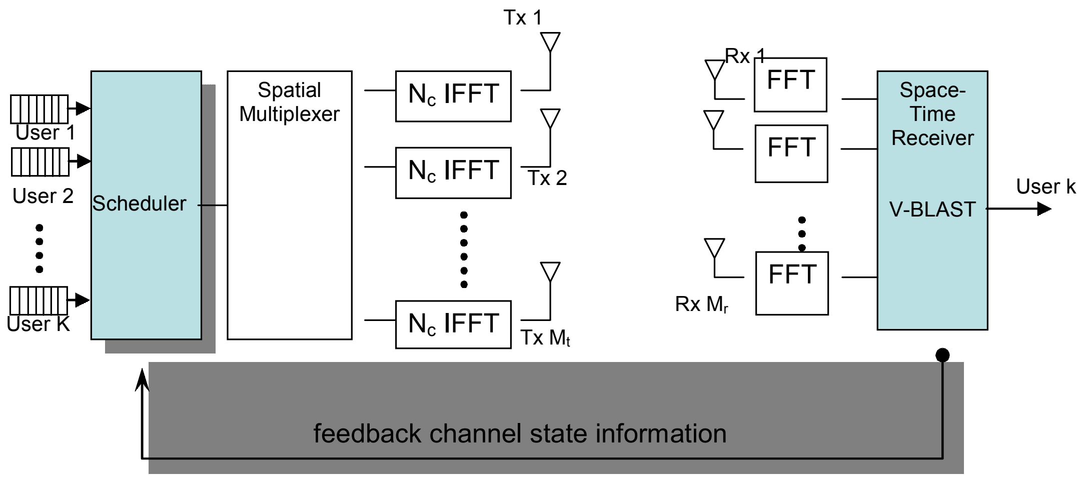

Figure 1 Downlink multiuser diversity with MIMO-OFDM communication links.

3. V-BLAST Detection Algorithm

The original V-BLAST detection algorithm [5] is a zero-forcing decision-feedback detector, which is described as follows. The transmitted vector for user k at subcarrier c is

$$\underline{a_c^k} = (a_{1,c}^k, a_{2,c}^k, \cdots, a_{M_t,c}^k)^T . \qquad (2)$$

We assume the $\boldsymbol{H^k}_{\boldsymbol{c}}$, a $M_r \times M_t$ matrix, is the channel's transfer function at the subcarrier c for user k. And $(h^k{}_c)_{ij}$ is the complex transfer function from transmit antenna j to receive antenna i at the subcarrier c. Hence, the received vector for user k with respect to subcarrier c is

$$\underline{y_c^k} = \boldsymbol{H_c^k} \underline{a_c^k} + \underline{v} . \qquad (3)$$

Using ZF detector, the ith ZF nulling vector is $w^k{}_{i,c}$, which is defined as the unique minimum norm vector satisfying

$$\underline{w^k}_{i,c}^{T} (\boldsymbol{H_c^k})_j = \begin{cases} 0, & j \geq i \\ 1, & j = i \end{cases}, \text{ for } i = 1, \ldots, M_t, c = 1, \ldots N_c \qquad (4)$$

where $(\boldsymbol{H^k}_{\boldsymbol{c}})_j$ is the j-th column of $\boldsymbol{H^k}_{\boldsymbol{c}}$. Therefore, $w^k{}_{i,c}$ is orthogonal to the subspace spanned by the contributions to $y^k{}_c$ due to those symbols not yet estimated and cancelled.

Thus, the output of ZF receiver is

$$\hat{y}^k_{i,c} = {w^k}^T_{i,c} y^k_{i,c} . \qquad (5)$$

The post-detection SNR for the *i-th* detected component at the *c-th* subcarrier of the transmitted symbol $a^k_{i,c}$ can be shown as

$$\rho^k_{i,c} = \frac{\left\langle \left| a^k_{i,c} \right|^2 \right\rangle}{\sigma^2 \left\| w^k_{i,c} \right\|^2} . \qquad (6)$$

Furthermore, the post detection SNR defined in (6) depends on the norm of nulling vector $w^k_{i,c}$ if the signal constellations used are the same.

4. Proposed algorithms

Determination of Channel State Information

Based on the V-BLAST detection algorithm and the property of post detection SNR, we know that the smallest nulling vector has highest SNR. Thus, the feedback CSI is determined by the norm of nulling vector. For 1-bit case, the feedback CSI uses 1 bit for each sub-channel. Thus, there are $M_t \times N_c$ bits for one frame or slot per user. Hence, we select the $r \times (1+\eta)$ sub-channels which have higher norm of nulling vectors, where r is the number of required sub-channel which is equal to (R^k_b / B). And η is the adjustment factor of data rate, which should be greater than 1. The algorithm for determining of CSI is as the follows:

Initialization:

$m^k_{i,c} = 0$, for all i and c

$R^k_b{}' = 0$

$S = \{(i,c): i = 1, \dots , M_t, c= 1, \dots N_c\}$

$CSI_k(i,c) = 0$ for $i = 1, \dots , M_t, c= 1, \dots N_c$

Recursion:

1. $(i^*,c^*) = \underset{(i,c)\in S}{\operatorname{argmin}} \left\| w^k_{i,c} \right\|^2$
2. $m^k_{i^*,c^*} = B$
3. $R^k_b{}' = R^k_b{}' + B$
4. $S = S \setminus \{(i^*,c^*)\}$
5. $CSI_k(i^*,c^*) = 1$

6. goto step 1 until $R^k_b{}' = \eta\, R^k_b$

For user k, $m^k_{i,c}$ is the sub-channel assignment, R^k_b is the date rate requirement, B is the number of bit per sub-channel within one slot, CSI_k is the channel state information matrix.

For 2-bits case, the feedback CSI uses 2 bits for each sub-channel. Thus, there are $2\times M^t\times N_c$ bits for one frame or slot per user. The algorithm of determining CSI is similar to 1-bit case. First, the norm of nulling vector is computed by using V-BLAST algorithm. Second, we check the post detection SNR by equation (6) and find out the sub-channels which satisfy the required SNR, called candidate sub-channels. Finally, we assign the CSI to 3 for the first 1/3 candidate sub-channels, and 2 for the second 1/3 candidate sub-channels, and 1 for the rest of candidate sub-channels. The CSI of sub-channels which dissatisfy required SNR are assigned to 0. We can use the same method for other case, for example, 3-bits case.

Scheduling

The idea for scheduling algorithm is to maximize the total number of allocated sub-channels and average SNR according to feedback CSI. That is to maximize the channel usage or channel capacity according to their data rate requirement. The scheduler has the candidate sub-channels for each user with simple ranking, for 2-bits case is 0, 1, 2, and 3. Hence the problem is a optimization assignment problem.

Let χ_k be the sub-channel assignment matrix for user k, i.e., if $\chi_k(i,c) = 1$ then the c^{th}-subcarrier of i^{th}-antenna is assigned to user k, otherwise $\chi_k(i,c) = 0$.

Problem model

$$\max \sum_{k,i,c} CSI^k_{i,c} \cdot x^k_{i,c} \qquad (7)$$

subject to:

$$x_{i,c}^{k} \in \{0,1\},$$

$$\sum_{k=1}^{K} x_{i,c}^{k} \leq 1 \qquad \forall\, i,c \tag{8}$$

$$\sum_{i=1}^{M_t} \sum_{c=1}^{N_c} x_{i,c}^{k} \leq (R_b^k / B) \quad \forall\, k \tag{9}$$

Constraint (8) is that the (*i,c*) sub-channel only assign to at most one user. Constraint (9) is that the number of allocated sub-channel can't exceed the requirement. The unknown variables are $x^{k}_{i,c}$ with total $K \times M_t \times N_c$ terms. Thus the scheduling problem is a integer linear programming problem[1].

5. Simulation Results

The multiuser diversity scheme introduced in this paper is investigated for a MIMO-OFDM system under a frequency selective fading channel. We assume the channel estimation is perfect in the computer simulation. The configurations we consider here are OFDM with 30MHz bandwidth, 32 sub-carriers, and a spectral efficiency of 12 bits/s/Hz. The QAM constellation is 16, i.e., B=4. There are 4 transmit antennas and 4 receive antennas. There are 5 users with same data rate requirement, and each user requires 20 sub-channels. The channel of each link contains three paths with exponential delay profile and the rms delay is τ_{rms}=20ns. In the simulation we use average received SNR defined as

$$\frac{1}{N} \sum_{i=1}^{N} SNR_i \; . \tag{10}$$

The actual SNR is the average received SNR for all assigned sub-channels, i.e., we only computer the allocated sub-channels for all users.

Figure 2 demonstrate the comparison of different number of bits used in feedback CSI. The optimal case is infinite bit to carrier all channel information to transmitter as

[1] The mixed integer linear programming problem can be solved by a freeware package, lpmex, for MATLAB. The package and information can be obtained at http://www.mathworks.com/matlabcentral/fileexchange/loadFile.do?objectId=98&objectType=file

shown in ‘all’-line. For 3-bits case, the actual SNR is closed to optimal case. For 2-bits case, there is less 0.5 dB than optimal case with average. There is 3.8 dB between optimal case and 1-bit case with adjustment factor η=0.3. Since the number of sub-channels exceeded SNR with 20 dB is 23%, or 30 channels, then the performance is dropped sharply for 20 dB case.

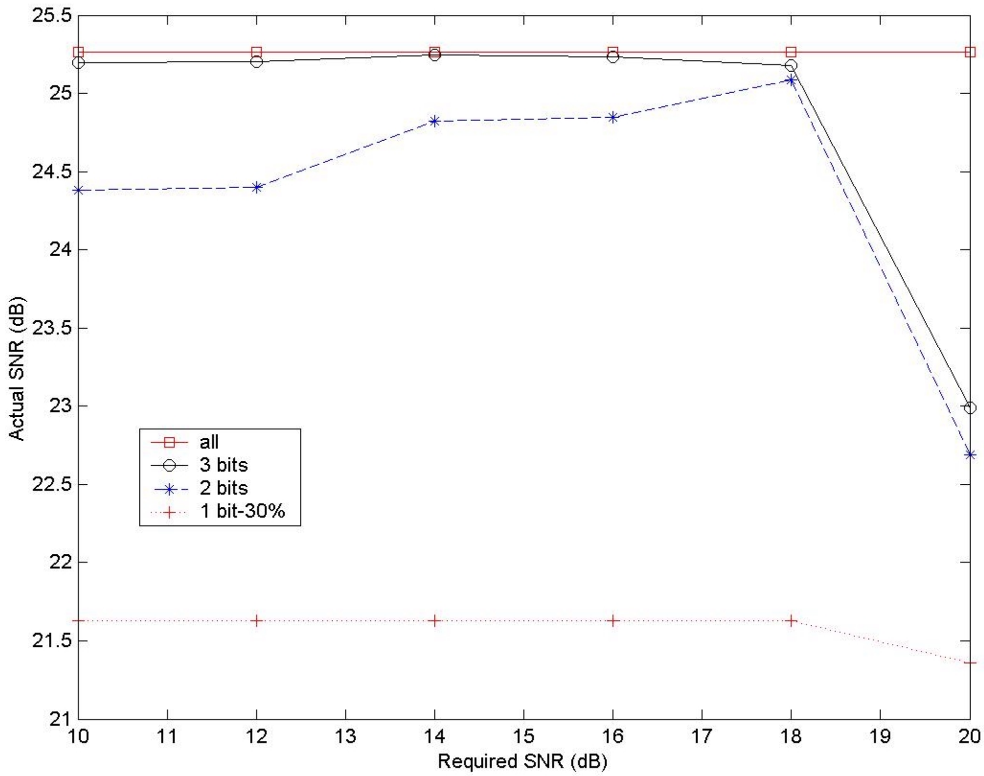

Figure 2 Performance of different number of bits for CSI.

We also compared the performance for different adjustment factors η, see Figure 3. The performance is increasing as η increase from 0 to 0.5. But the performance is unstable for η equals to 1. The reason is that if we send all satisfy sub-channels without any ordering then we can’t guarantee the received SNR.

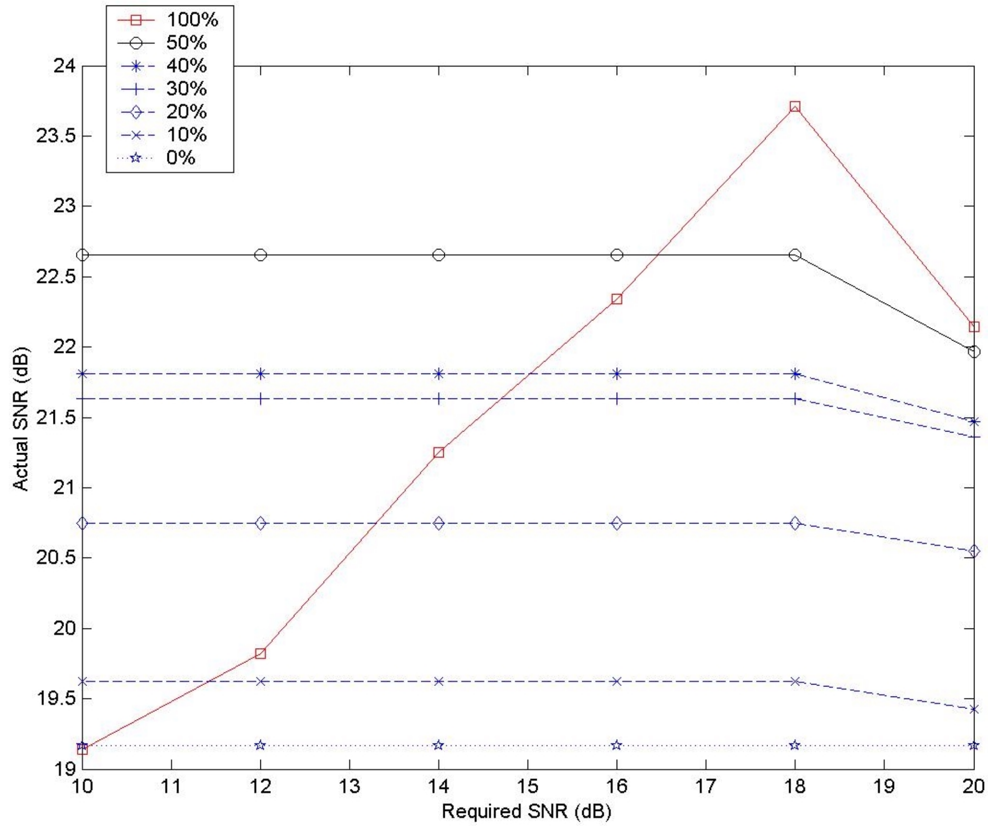

Figure 3 Performance of different adjustment factors η for 1-bit case.

6. Conclusion

In this project we apply the multiuser diversity to V-BLAST based MIMO-OFDM systems with limited feedback CSI. We examined the number of feedback bits effect in the multiuser diversity scheme. From this project, we studied the multiuser diversity technique and a resource allocation scheme for MIMO-OFDM systems. We assumed the QAM-constellation is constant. We only optimized within a frame or a slot. The adaptive modulation schemes and fairness scheduling algorithms within several frames are a topic for future investigation. The other types of receiver, such as MMSE, might be considered for further study.

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